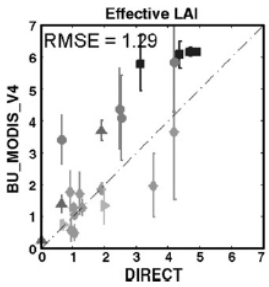
Model-based quality assurance of validation protocols for land products (FAPAR, LAI & Albedo)

Jean-Luc Widlowski

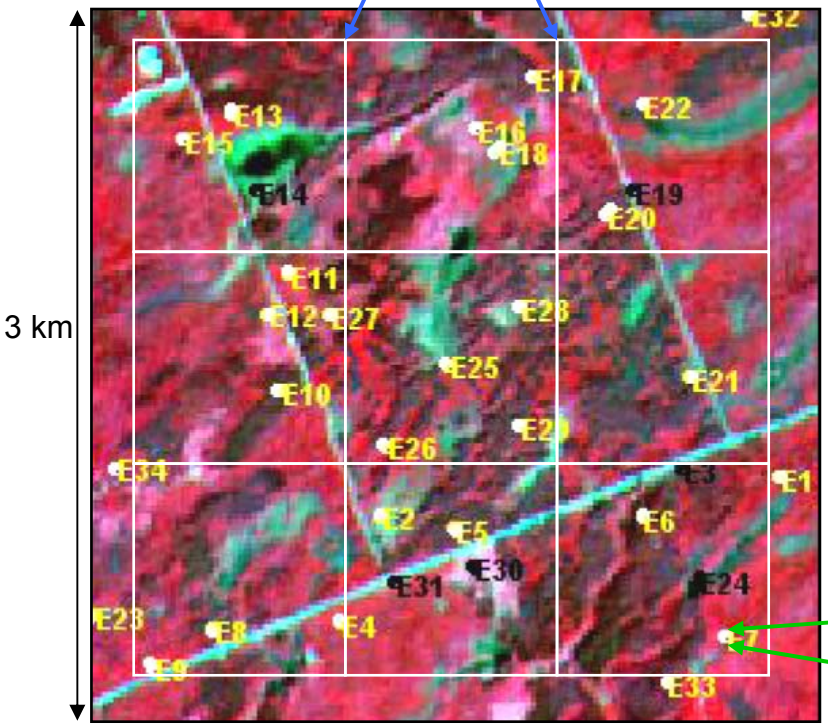
'validation' methodology



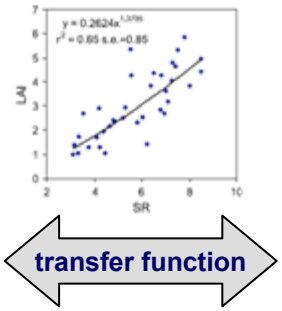
$\sigma_{LAI} \approx 15\text{-}25\ \%$

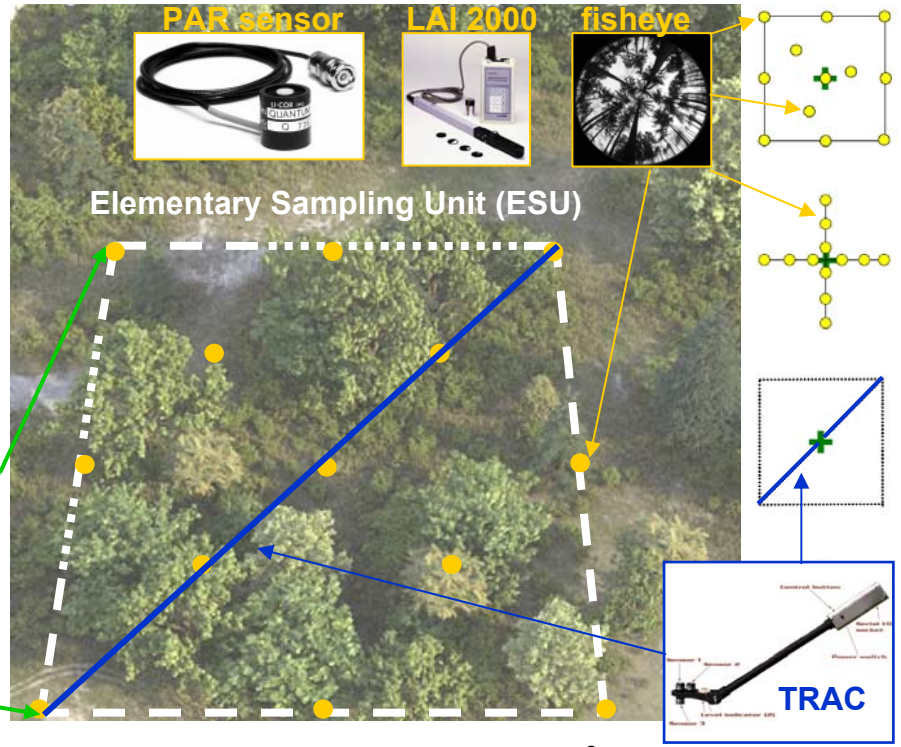
$\sigma_{FAPAR} \approx 15\ \%$

1. retrieve LAI, FAPAR at ESU level.
2. establish transfer function to high resolution space observations.
3. upscale to medium resolution space sensor scale (3x3 pixel matrix).



SPOT image with ESU locations indicated





ESU size is typically 20x20 to 30x30 m^2

www.onyxtree.com/gall-borrett1.html, daac.ornl.gov/data/global_vegetation/LAI_VALERI_Canada/comp/Larose2003FTReport.pdf, Fernandes et al, 2004, Weiss et al., 2007

land product validation caveats

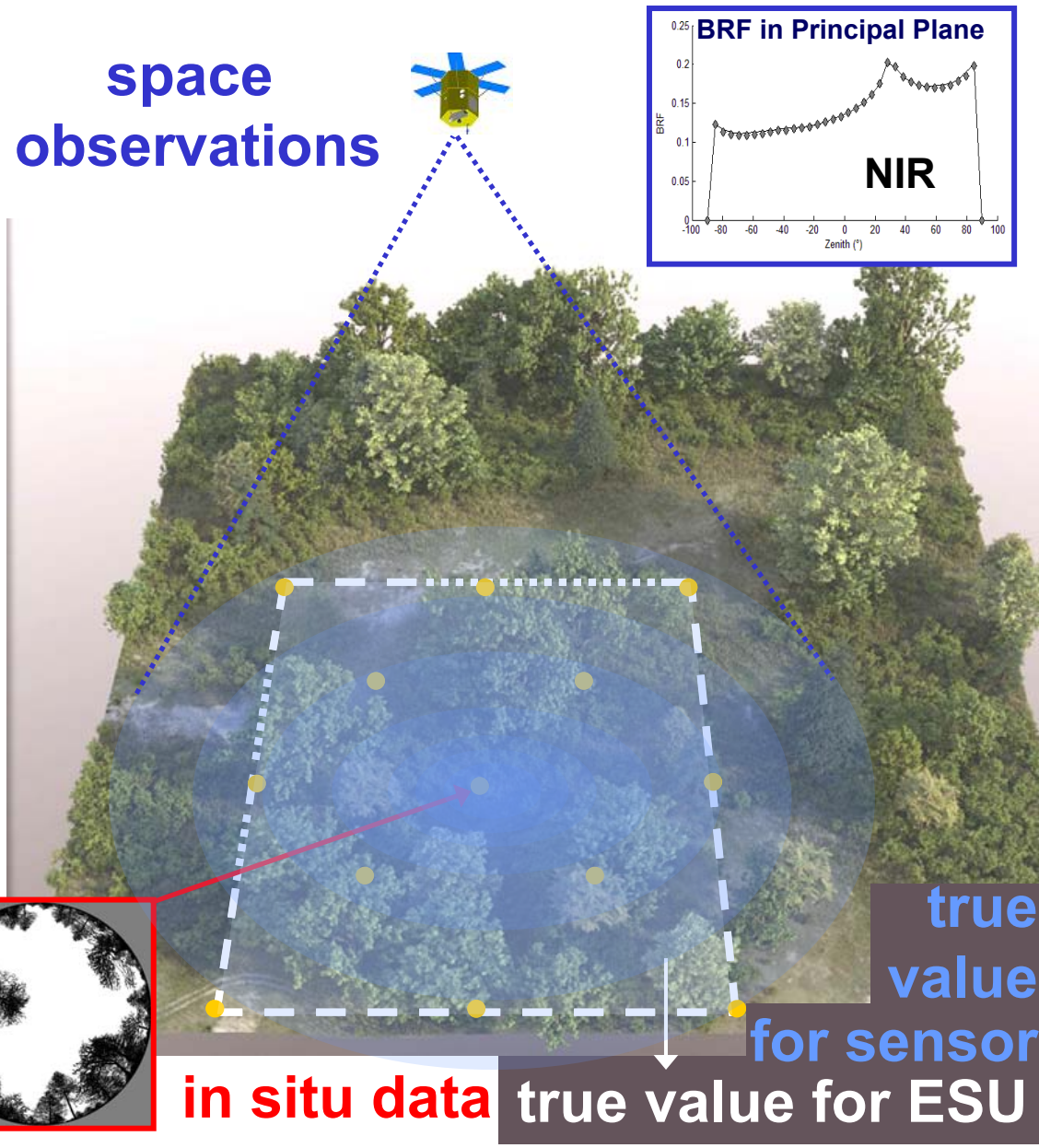
- field 'validation' is mostly 'indirect' yielding products based on *in situ retrievals* rather than direct measurements.
- definitions of *space retrieved* FAPAR and albedo products can differ or relate to spectral properties (and illumination conditions) that don't exist in the field (at time of overpass).
- FAPAR, LAI & albedo under ambient conditions may not be the desired quantities to feed downstream applications.

Need for a traceable quality assurance system allowing to assess both the accuracy and precision of space and *in situ* retrievals irrespective of product definitions.

3-D Monte Carlo RT models

- are physically-based
- can deal with natural & artificial targets
- handle arbitrary complex canopy architectures
- simulate air, space and in-situ measurements
- function as virtual labs due to modular structure
- emulate simpler models

Must ensure that these RT models are accurate!



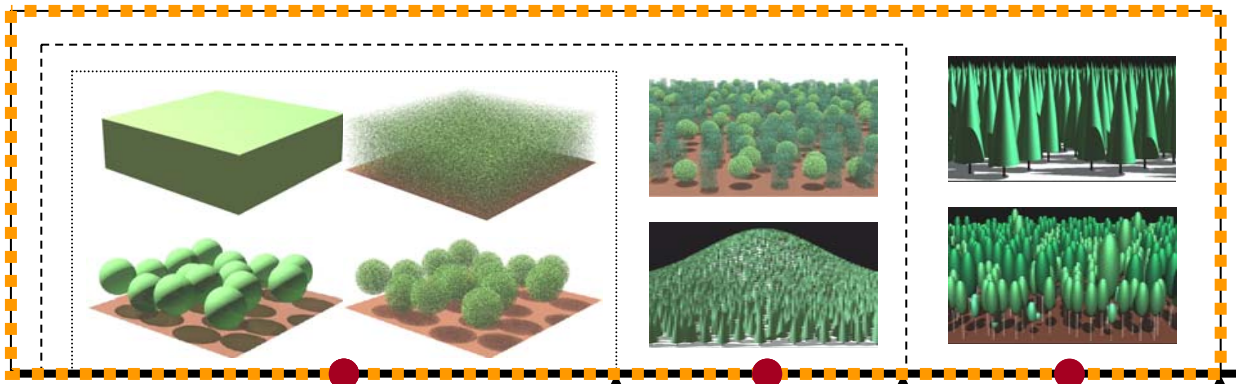
landscape image from http://www.onyxtree.com/gall-borrett1.html

RAdiative transfer Model Intercomparison

community standard

automate benchmarking process

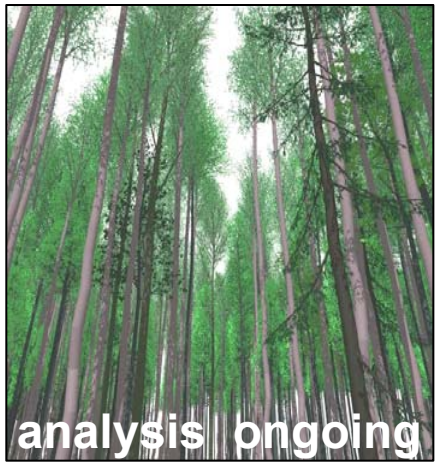
RAMI On-Line Model Checker (ROMC)



reference data set

increased realism

summer birch stand



(2007)

RAMI-1 (1999)

RAMI-2 (2002)

RAMI-3 (2005)

RAMI-IV (2009)

8 models

substantial differences amid 1D and 3D models

13 models

still differences amid the 3D models

18 models

excellent agreement; especially for 3D MC models

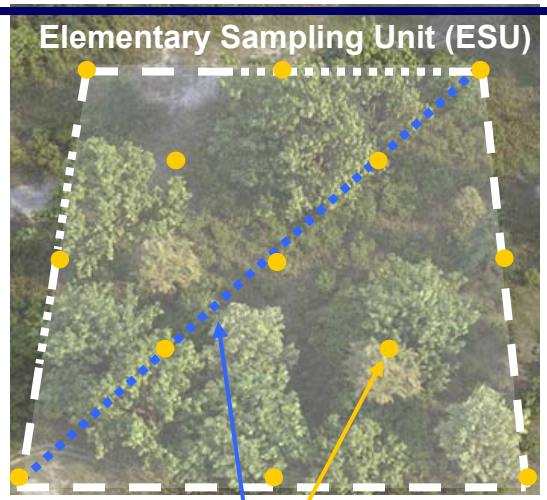
Set of 6 'credible' 3-D Monte Carlo models (~1% deviation)

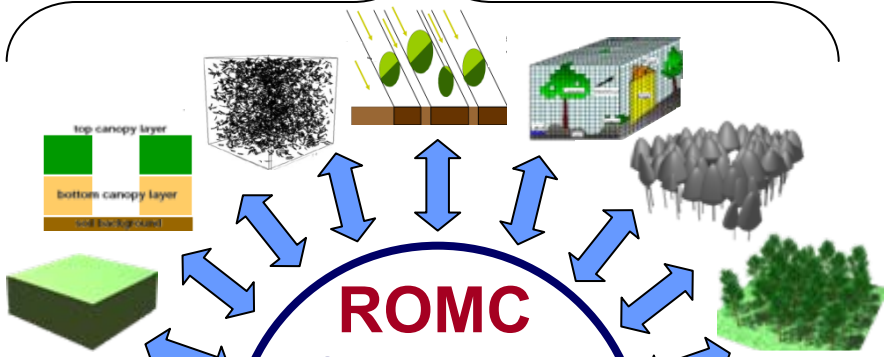
- satisfy energy conservation
- identical to analytical solutions
- versatile and few assumptions

Pinty et al. (2001, 2004) JGR; Widlowski et al., (2007) JGR, (2008) RSE

RT model-based quality assurance

space sensor → data → retrieval algorithm → space product





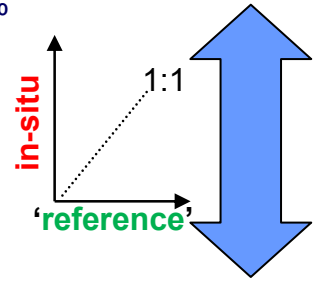
ROMC
reference (±1%)
3-D MC RT models

if (ref – prod)^2 > (σ_{ref})^2 + (σ_{prod})^2 then difference is significant

FAPAR, LAI, etc.

reference product

σ_{ref}≈1%



in situ sensor → data → retrieval algorithm → in situ product

σ_{data}≈1%

σ_{prod}

FAPAR, LAI, etc.

Images courtesy of: D. da Silva, J-P. Gastellu-Etchegory, Y. Govaerts, T. Quaife, and W. Verhoef

Widlowski et al, 2010, RSE (Submitted)

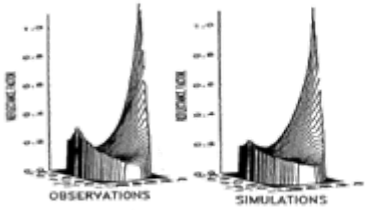
RT model-based quality assurance

space sensor → data → retrieval algorithm → space product

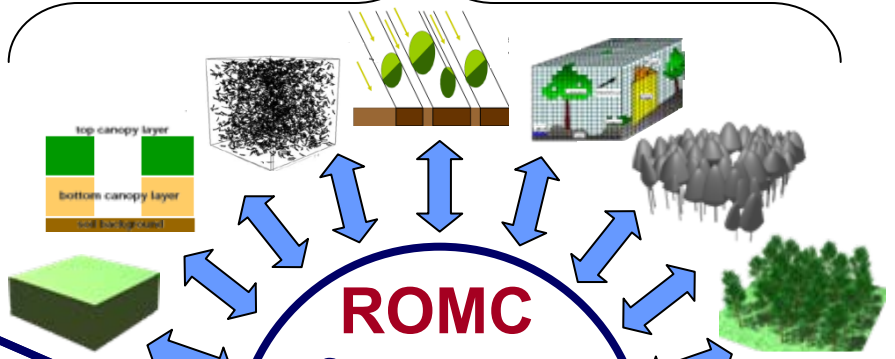
σ_{prod} FAPAR, LAI, etc.

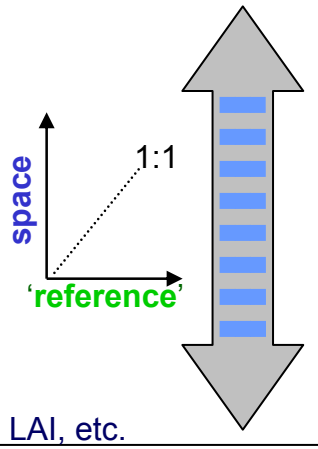
σ_{data}

θ_0=56°



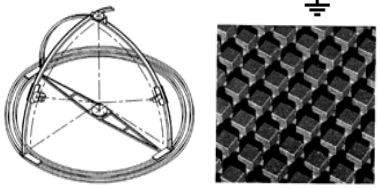
I3RC atmospheric RT model





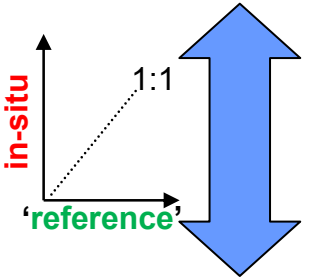
ROMC
reference (±1%)
3-D MC RT models

reference laboratory standard(s)



Govaerts, 1997

FAPAR, LAI, etc.
reference product
σ_{ref}≈1%



in situ sensor → **data** → **retrieval algorithm** → **in situ product**

σ_{data}≈1%

σ_{prod} FAPAR, LAI, etc.

Images courtesy of: D. da Silva, J-P. Gastellu-Etchegory, Y. Govaerts, T. Quaife, and W. Verhoef

Widlowski et al, 2010, RSE (Submitted)

Example: in situ FAPAR estimations

reference quantity, **R**

$$FAPAR = 1 - T + \alpha T - R + H$$

estimator quantities, **Q**

4-Flux

$$A\updownarrow = 1 - T + \alpha T - R$$

3-Flux

$$A\updownarrow_{\alpha=R} = 1 - T + RT - R$$

$$A\updownarrow_{\alpha=0} = 1 - T - R$$

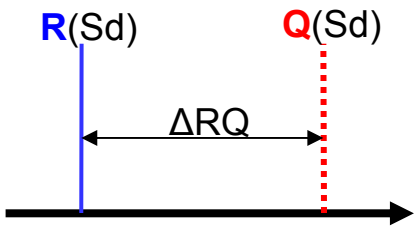
2-Flux

$$A\downarrow = 1 - T$$

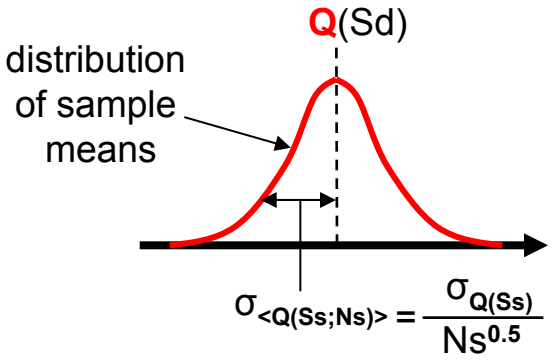
$$A\downarrow_{0} = 1 - T^{0}$$

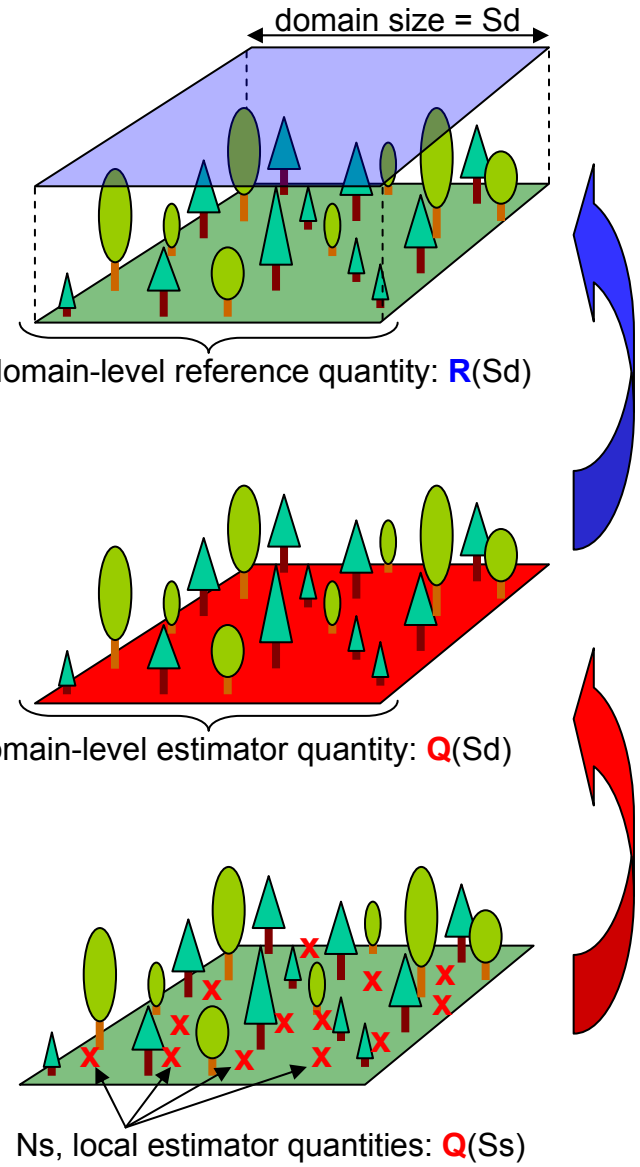
$$MSE = \Delta RQ^2 + \frac{\sigma^2_{Q(Ss)}}{Ns}$$

Transfer bias



Sampling error





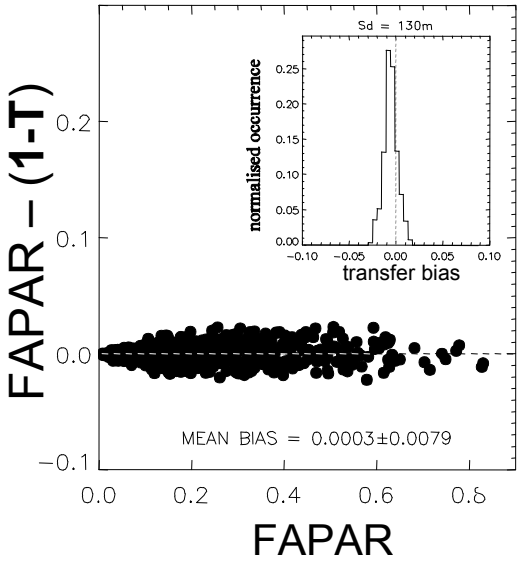
Widlowski, On the bias of instantaneous FAPAR estimates in open-canopy forests, AFM, 2010

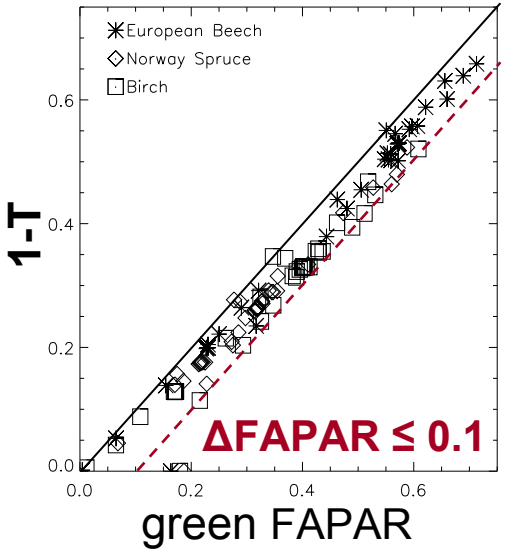
transfer bias

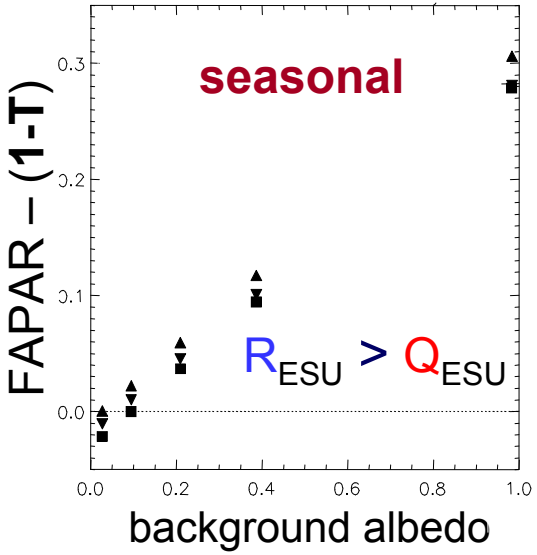
The transfer bias is due to the algorithm one choses to estimate the reference quantity within the ESU:

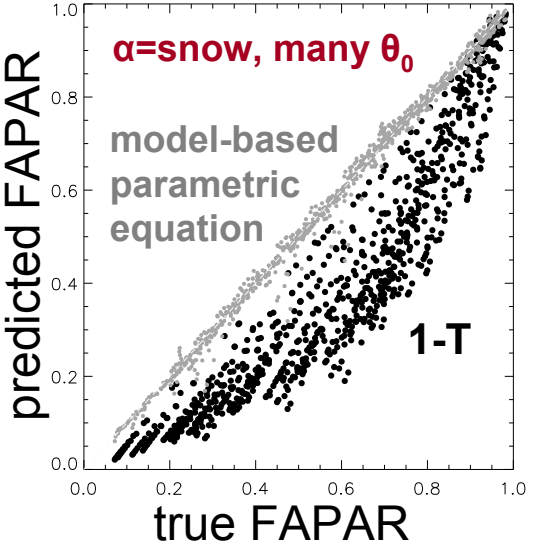
Transfer bias = $R_{ESU} - Q_{ESU}$

- 2-flux estimator (**1-T**) best during summer conditions
- bias of **1-T** with respect to other FAPAR definitions
- seasonal (& daily) change in transfer bias of **1-T**
- better FAPAR estimators via RT model simulations









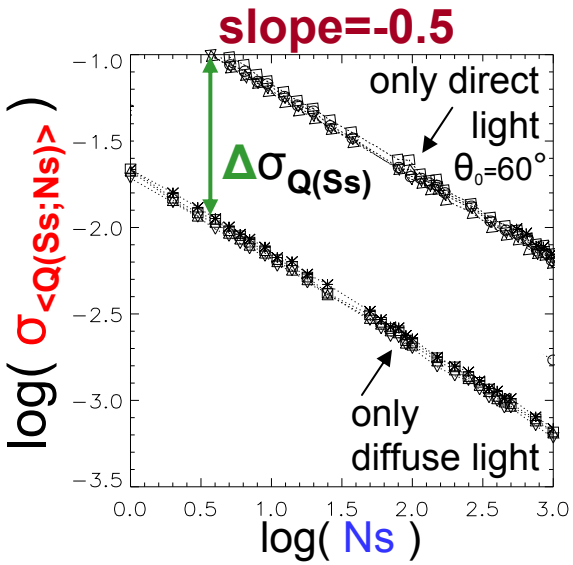
Widlowski, On the bias of instantaneous FAPAR estimates in open-canopy forests, AFM, 2010

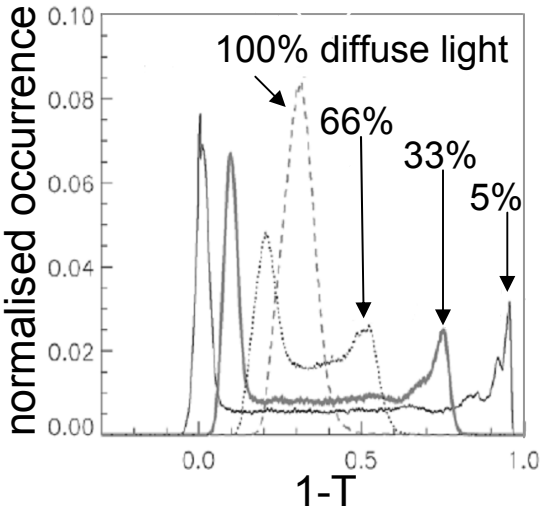
sampling error

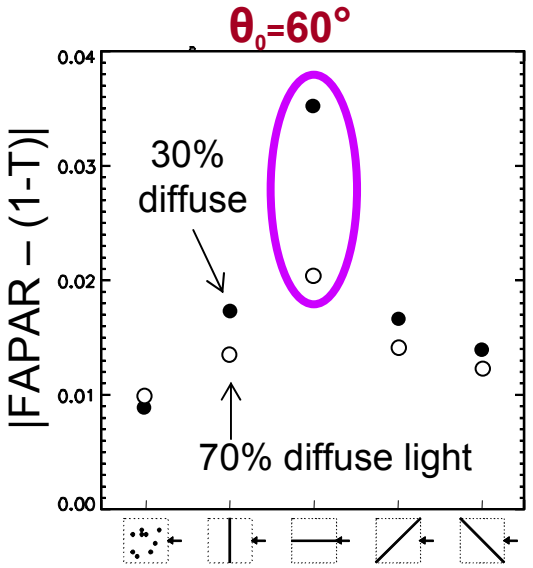
The sampling error relates to the spatial variability of the quantity of interest (Q) versus the sample number (Ns) taken within the ESU:

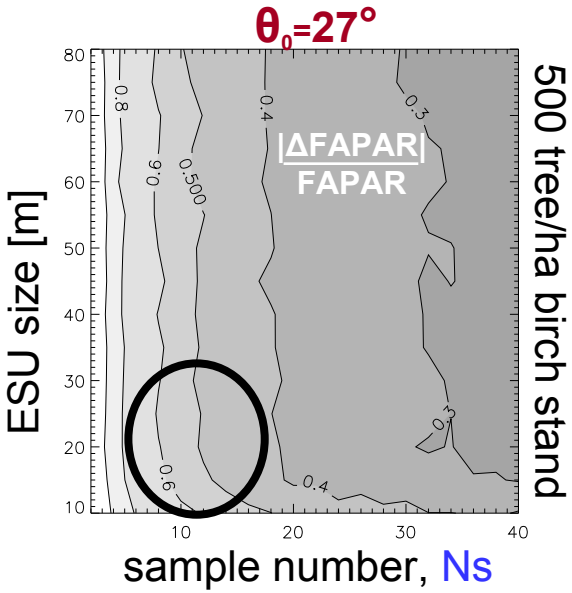
$$\sigma^2_{<Q(Ss;Ns)>} = \sigma^2_{Q(Ss)} / Ns$$

- to reduce $\sigma_{<Q(Ss;Ns)>}$ by a factor 10 requires 100·Ns
- up to **50% error** in FAPAR with current field protocols
- transects parallel to solar azimuth are to be **avoided**.









Widlowski, On the bias of instantaneous FAPAR estimates in open-canopy forests, AFM, 2010

recommendations on best practices

space ‘pixel’ scale

- accuracy & precision of transfer functions & overall up-scaling methodology

ESU scale

- accuracy & precision of a given field protocol (illumination, biome type, sampling number and scheme, background brightness & spatial variability)
- optimal ESU size, instrument choice, illumination conditions, tower height…
- contribution of field instrumentation on high resolution space measurements,
- impact of practices, like measuring incident radiation in forest clearings.

RT model-based QA is based on an exact knowledge of all structural, spectro-directional and illumination related characteristics of “realistic” canopy scenes.

To use a RT model-based QA approach on actual test sites requires *very detailed site inventories* in order to match both space & in situ observations to within the uncertainty of the observing sensors.

missing inventory data

1) canopy architecture (3-D)

- shoot/leaf shape & dimensions
- shoot/leaf orientation
- foliage distribution in crowns
- crown shapes
- branching angles & density
- woody content (live & dead)

terrestrial laser scanning
(combined with airborne)
→ topography

2) scattering directionality and its spatial variability

- foliage (leaves & needles)
- bark (stem & branches)
- background

lab/field goniometers
new in-situ instruments?

3) illumination anisotropy

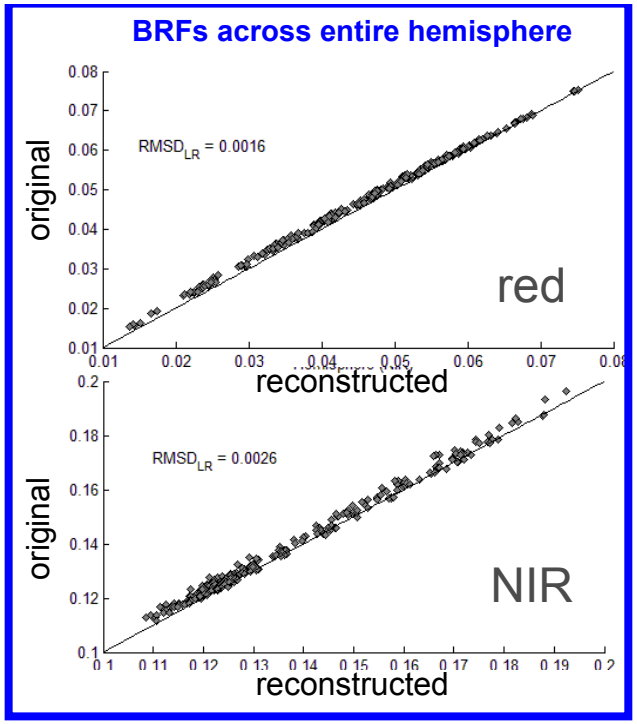
field goniometer with outward pointing sensors

Widlowski et al, 2010, RSE (Submitted)

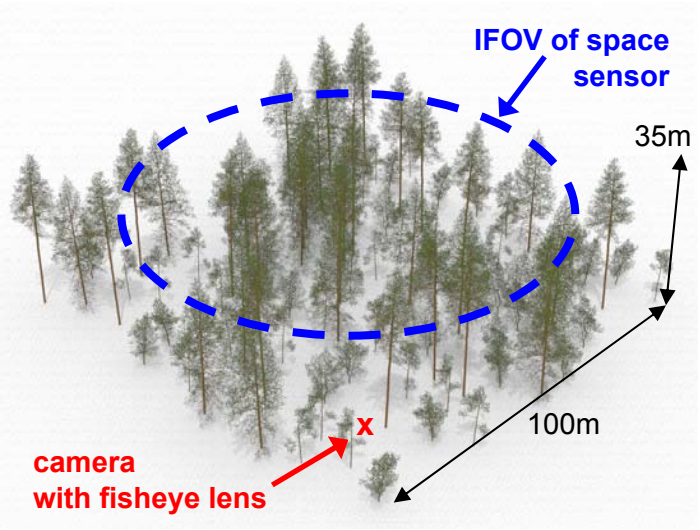
quality of structural reconstruction

Current limitations of actual test site reconstructions:

- reconstruction of closed-canopy forests
- characterisation of leaf/wood scattering anisotropy
- spatial variability of leaf/wood/background anisotropy

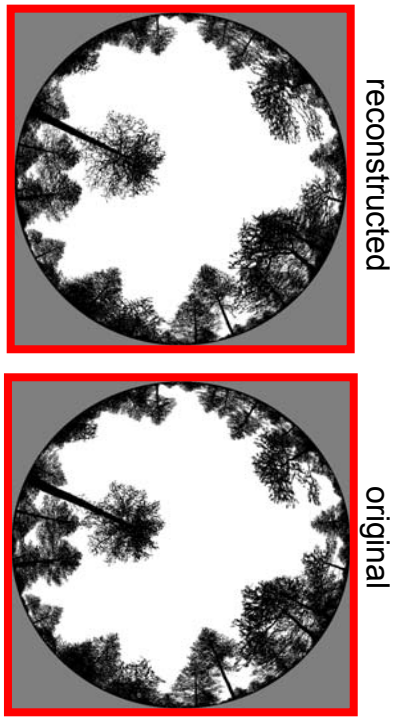


domain scale



Coté et al., 2009, RSE

in-situ scale

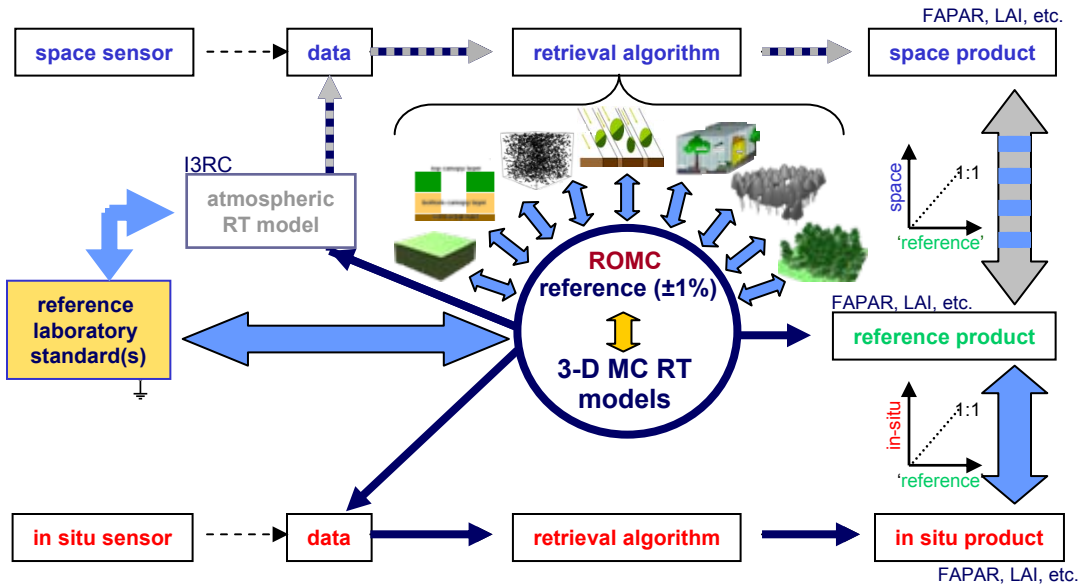


Conclusions

Validated 3-D MC RT models enable setup of traceable QA system for quantitative EO products and their field 'validation' techniques.

Benefits:

- can account for diverging space product definitions,
- can account for acquisition scheme of space data and EO sensor characteristics,
- can assess/improve quality of field 'validation' protocols,



- realism of 3D canopy reconstructions will benefit from improved inventories of structural & spectro-directional site characteristics.
- site-specific reconstruction will allow comparison with actual data.

Widlowski et al, 2010, RSE (Submitted)

THANK YOU

http://rami-benchmark.jrc.ec.europa.eu/

http://romc.jrc.ec.europa.eu/

Jean-Luc.Widlowski@jrc.ec.europa.eu